Assimilation of Remote Sensing into DELFT3D

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Award Number : N00014-05-C-0313

LONG-TERM GOALS

Much effort has gone on in the hydrodynamic modeling community to build oceanic models of the littoral region. The spectral shoaling wave SWAN model, the phase-preserving shoaling wave Boussinesq models, and the DELFT3D flow model are all examples of such development. All of these require a description of the local environment as input in order to be able to run the models and generate either a more complete description of the current environment, or a prediction of future conditions.

In order to make these models useful to the operational Navy, there must be some way to generate the required model inputs in locations where the local environment has not been completely characterized, if at all. Remote sensing data provides an intriguing possibility to generate these inputs, allowing the Navy to utilize these models anywhere that the remote sensing data is available. However, directly estimating the required input values from remote sensing data can be very difficult if not impossible. Another possibility is to assimilate the remote sensing data into the model. Figure 1 illustrates what such assimilation means (green arrows), and compares it to directly estimating the required environmental information (red arrows). Remote sensing assimilation requires that we have an image simulation capability that can take the model *outputs* and use them to generate a simulated remote sensing data set. The assimilation process then derives the model *inputs* such that the simulated remote sensing data set has the closest possible match to the actual remote sensing data set. When the simulated and actual data match, we then take the model outputs as an accurate representation of the local environment. An advantage of this assimilation approach is that it does not require developing algorithms for directly estimating local environmental parameters from the remote sensing data (such as the top box in Figure 1), but only requires the model, a tool for simulating remote sensing data, and the tool that translates differences between the simulated and actual remote sensing data into changes into model inputs such that the loop converges. This latter box is often called the adjoint of the model; in essence it runs the model backwards, translating errors in the output of the model to errors in the inputs.

The long-term goal of this project is to build an assimilation system for the Delft3D model that can be used operationally by the Navy. It will be able to utilize any remote sensing data that is available, and automatically generate the model inputs required to reproduce the remote sensing imagery. It is envisioned that this will give the Navy the capability to utilize Delft3D anywhere in the world where appropriate remote sensing imagery can be collected

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **Assimilation of Remote Sensing into DELFT3D**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **General Dynamics Advanced Information Systems ,1200 Joe Hall Drive, P.O. Box 990,Ypsilanti,MI,48197**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

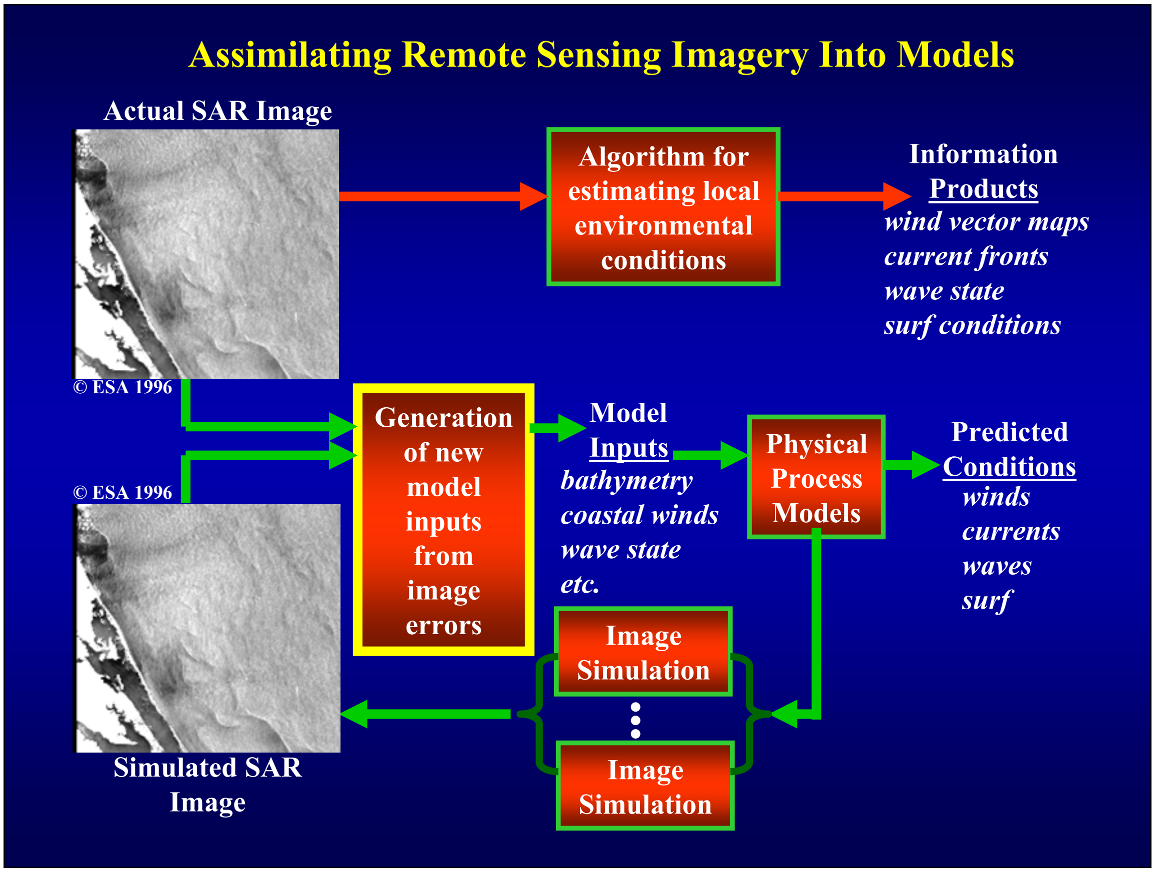


Figure 1: Flow diagram comparing direct estimation of environmental parameters from remote sensing imagery (top, red arrows) to assimilation of remote sensing imagery into a physical process model such as Delft3D (bottom, green arrows).

OBJECTIVES

The program has three objectives.

(1) ***Development of the Delft3D adjoint model.*** Develop the approach to translate the errors between the simulated and actual remote sensing imagery into modification to the model input parameters such that the system converges.

(2) ***Development of the assimilation system.*** Put the adjoint model together with Delft3D and existing simulation tools to build the overall assimilation system.

(3) ***Validate the system***. Using either simulation or data collected at a site with ground truth, run the assimilation system to estimate local environmental conditions and compare to the "ground truth". Two sites being considered for validation are the Army Corp of Engineers Field Research Facility at Duck, N.C., and the site of the on-going ONR NCEX experiment off the west coast of California

APPROACH

To develop the adjoint for the Delft3D model, we will first determine which input parameters will be "adjusted" as part of the assimilation process, and which will be estimated initially and then set constant. It is not realistic (either computationally or from a convergence constraint) to assume that we can adjust all of the Delft3D model inputs simultaneously. Thus some will need to be estimated once only. Once the set of parameter that will be modified is known, we will then develop the adjoint equations that translate errors in the model output to errors in these parameters. This will be derived by using the analytical equations that Delft3D solves and performing the differentiations on these required to move from output changes to input changes. Once these are derived, the final step will be to code up these adjoint equations. Typically this is down by actually using the forward model source code, but implementing it in reverse order.

Once the adjoint code is developed, to satisfy the second objective we will take the Delft3D forward model, existing image simulation codes for radar, optical and multi-spectral remote sensing imagery, and the adjoint model, and put them together into a single system. We will also implement the iterations required to converge the system to a solution. We anticipate that this will be a conjugate gradient search, where the adjoint code will be considered as generating the error gradient with respect to the input model parameters being changed.

To achieve the final objective, we will first use simulation to test the end-to-end system to achieve three milestones: (1) From a single point observations of a current profile, reconstruct a single input flow term into the domain; (2) From one or more point observations of current profiles we will reconstruct input flow along a boundary of the domain; and (3) we will incorporate remote sensing signatures (either with or without *in situ* observations of the currents) to reconstruct the input flow along boundaries of the domain. Then, if time and funding permits, we will test the system with actual data at on of the sites mentioned above. For the simulation work, we will use a 100km X 200km region off the east coast of the U.S. near Duck, N.C. so we can use realistic input values measured at the Army Corp of Engineers Field Research Facility there.

WORK COMPLETED

The Delft3D code has been acquired and has been implemented in a forward model run mode on both Unix and Linux systems. This involved some effort on working out the agreement between General Dynamics and Delft Hydraulics, as well as a fair amount of interaction with Deflt as to code implementation issues. In addition the Princeton Ocean Model (POM) has been acquired and implemented in a forward model run mode on both the Unix and Linux systems. Figure 2 shows results, for the simulation region we will use in this program, of forward model runs for both codes. Note that they are essentially equivalent.

The Delft3D adjoint equations have been analytically derived (and checked twice). Using the POM forward code as a starting point, the adjoint equations have been implemented by modifications of the forward code. These adjoint codes and forward codes (for POM) were then put together using a steepest descent algorithm that takes small steps in the direction of the gradient of the error as estimated by the adjoint code. This system will be the core of the final program; the only major change will be to convert to a conjugate gradient search instead of steepest descent, and to implement a one-dimensional search instead of taking small steps in the gradient direction.

Using the system described above, the first milestone has been achieved (see Results section below). Thus we are able to correctly derive a single input flow term coming into the domain from a single observation of the current profile (taken within the domain) This has verified that the adjoint equations have been implemented correctly, and are correctly estimating the gradient term.

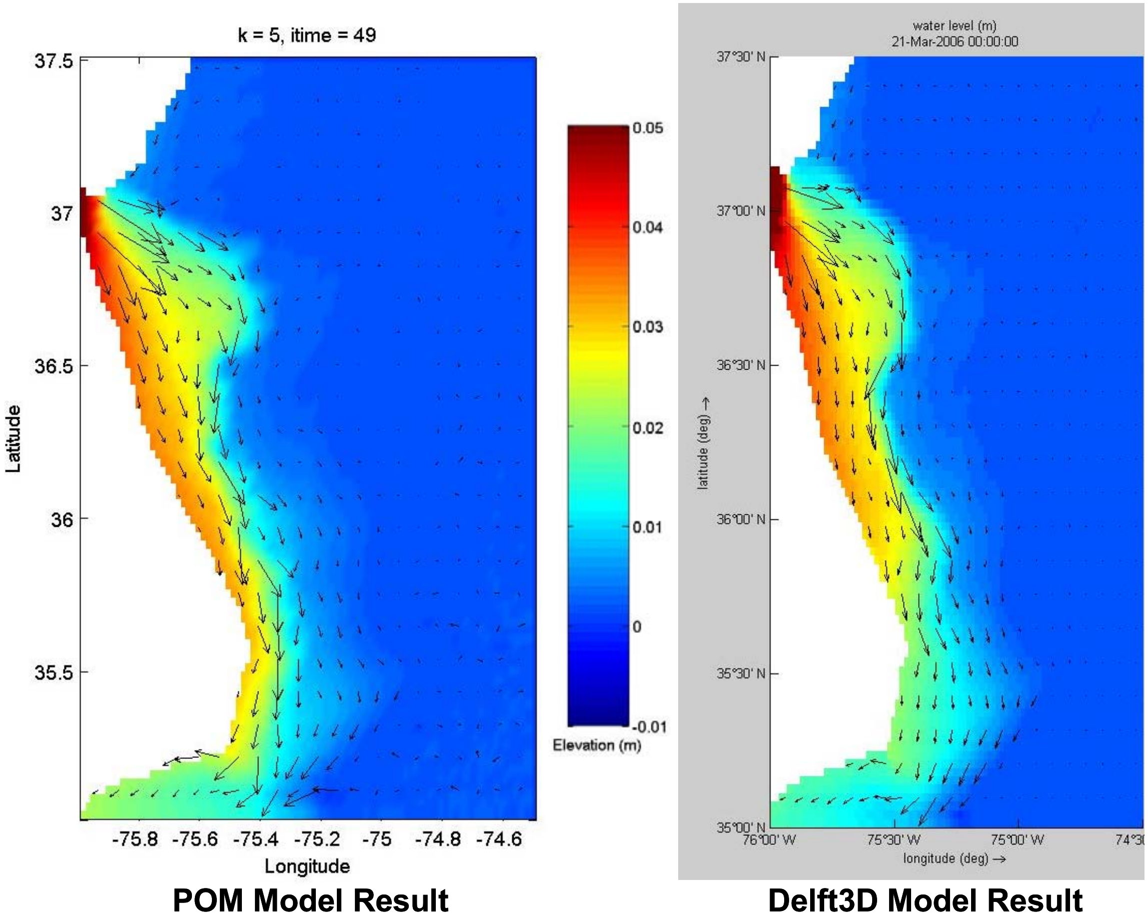


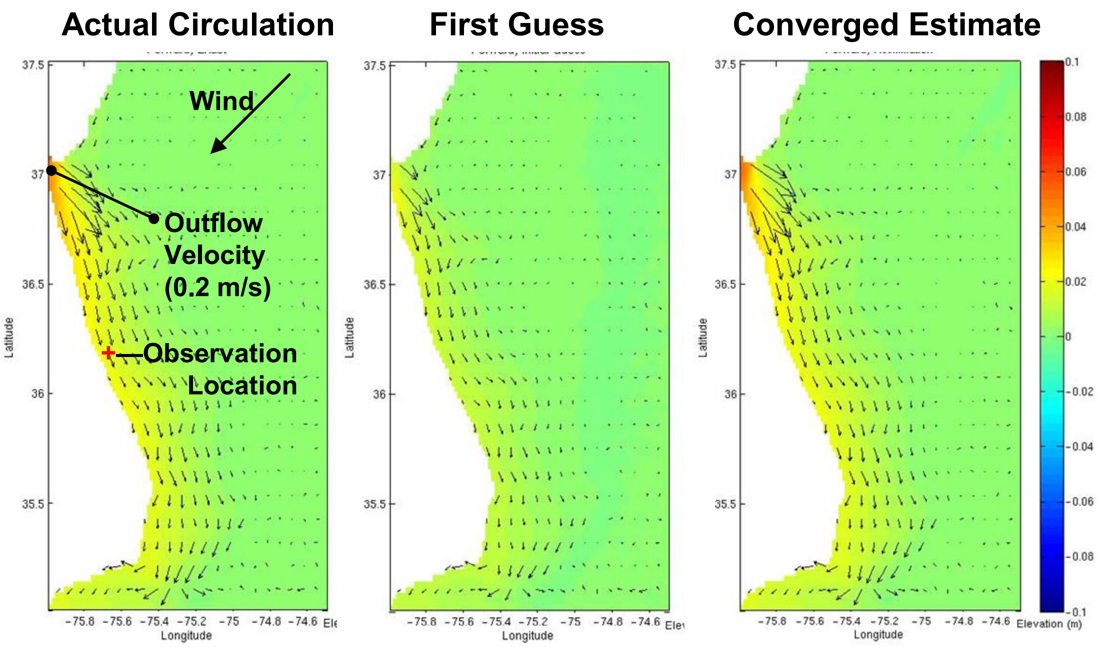
Figure 2: Comparison of POM results (left) with Delft3D result (right) for the coast off of Duck N.C. Note that they are essentially equivalent

RESULTS

The major result this year is development of a system that incorporates the Delft3D adjoint code with the forward POM model, and is able to automatically derive the input flow required to generate a single current profile observed within the domain. Figure 3 shows the result of this first milestone. The left figure shows the "ground truth" for the simulation, the middle figure shows the initial guess (which is a guess on the input flow rate run through the forward model), and the right figure shows the automatically converged result which is essentially identical to the "ground truth". However this is really a single parameter convergence test, so Figure 4 shows the input flow generated from the assimilation code starting from two different initial guesses (one too high and one too low) as a function of iteration. Note that both converge to the correct answer. This indicates that the adjoint equations have been derived and implemented correctly, so we can move on to the other milestones.

IMPACT/APPLICATIONS

If successful, the resulting assimilation system will allow the operational Navy to utilize Delft3D models in most places in the world for monitoring of local littoral environmental conditions and for planning of future operations.



Plots show Velocity and Surface Elevation

Figure 3: Results from the first run of the assimilation code. The left image shows the "ground truth" derived from the POM forward model. The middle image shows the first guess which results from assuming a value for the input flow, then running the forward model. The right image shows the automatically converged estimate from the assimilation code – note that it is essentially equivalent to the ground truth.

RELATED PROJECTS

There are no ongoing related projects that are closely identified with this project.

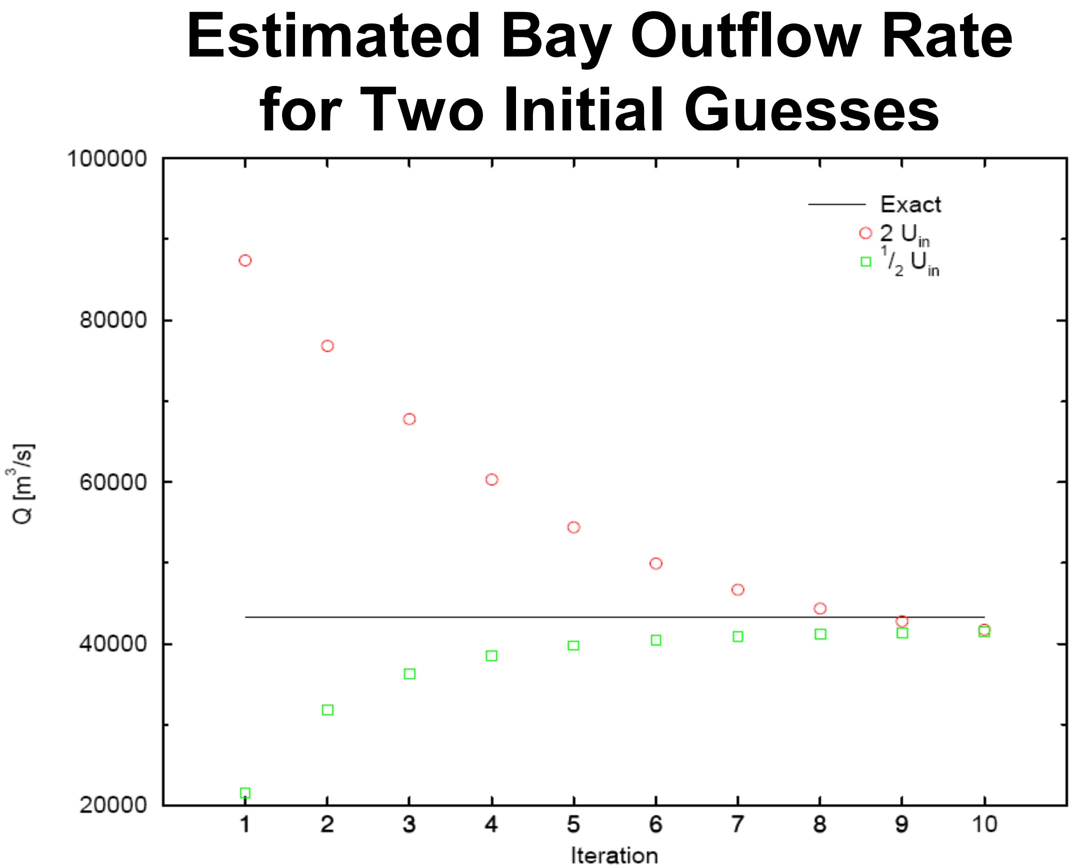


Figure 4 : Plot of the flow values as a function of iteration of the assimilation code for an initial guess that was too high (red) and one that was too low (green). Both converge after approximately 10 iterations to the correct answer.